6.4 Technical Review
March 2014

Project: **Modeling Sensing and Forecasting Ocean Optical Products for Navy Systems: Tactical Ocean Data System (TODS)**

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Modeling, Sensing and Forecasting Ocean Optical Products for Navy Systems- TODS

Summary of Capabilities, Accomplishments and Plans

Summarize FY13-14 Delivered Capability

- FY13/14 delivery provides naval operations with a real time and forecast optical characterization capability (surface only) of the battlespace including water clarity, diver visibility (visual detection /vulnerability, lidar penetration depth, SDV vulnerability – BioCast v1.0 VTR delivered FY14Q1 – OPTEST to start soon.
- Planned FY14 delivered capabilities include the generation of a real-time 3D optical environment / volume by fusing gliders, satellites and physical models (3DOG) to support underwater MIW operations with vertical diver visibility and laser/EO (AQS-24) imaging system performance (EODES) – No 3D optical forecasting
- Products used by MIW (HM-14,HM-15) Reach Back Cells for mission planning and operations.

Summarize FY14 Plans

- Complete 3DOG v1.0 delivery w/ VTR & EODES AQS 24 system performance software.
- Start BioCast v2.0 software modifications and testing to use 3DOG Optical Volume as initial field (instead of homogeneous volume) for enhanced (with layer information) forecasting.
- Install and test Solver SDK software license at NAVO for glider/satellite optimization of 3DOG coefficients.

FY13-14 Accomplishments/Challenges/Issues

- BioCast improvements for coastal numerical stability.
- Bathygen software developed/delivered for bathy file consistency (HDF/netCDF) required as input to BioCast and 3DOG
- 3DOG integration/testing complete and validation underway
- Glider optimization upgrade (evolutionary solver) for improved accuracy and processing speed in tuning 3DOG coefficients
- EODES upgrade to I/O to read in 3DOG optical volumes directly replacing IDL wrapper.
- OpEval was performed due to software improvements for both BioCast and 3DOG during Trident Warrior (July 2013)

Challenges/Delays due to issues encountered and successfully addressed with needed operational software enhancements

Funding

($K)	FY11	FY12	FY13	FY14
TODS	300	150	235	215
Total	300	150	235	215

Modeling, Sensing and Forecasting Ocean Optical Products for Navy Systems- TODS

FY13-14 Major Objectives & Milestones

MS Event/Action/Improvement Objective	Completion and/or Delivery Quarter/FY	Description of Capability Completed and/or Delivered
Optical Forecast – BioCast v1.0	**Delivered w/ VTR 1QFY14 OPTEST to start soon**	**Provides forecasts of surface coastal optical properties for water clarity, diver visibility (visual detection/vulnerability) and lidar penetration depth**
Bathygen v1.0	**Development Completed and delivered 1QFY14**	**Software developed to consistently generate bathymetry from supplied DBDB2 and GEBCO databases to match satellite grid from AOPS for BioCast and 3DOG.**
3D Optical Volume Generator v1.0 3DOG	**VTR 3QFY14 OPTEST to follow**	**Provides forecasts of the 3D optical environment by fusing gliders, satellites and ocean models in support MIW diver and laser imaging operations.**
EODES v1.0 (AQS-24)	**Delivery 4QFY14**	**Provides performance surfaces to support underwater laser imaging systems (AQS/EODES) for AQS24, airborne laser systems (ALMDS), EO bathy systems, and diver operations (visibility/vulnerability)**

Modeling, Sensing and Forecasting Ocean Optical Products for Navy Systems- TODS

Milestone Chart

Tactical Ocean Display System (TODS)																
	FY11				FY12				FY13				FY14			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
(1) Forecast Optical Properties (3D Biocast v1.0)					S				C	V	O	C	V	O		
(2) 3D Optical Generator (3DOG) w/ AQS-24 System Performance (EODESv1.0)								S					C	V C	V	O
(3) BioCast v2.0														S		
(4) Exercises / Demonstrations					D		D				D				D	-

Milestones indicate **V**TR panel-accepted and **O**PTEST Rpt Completed

1. BioCast v1.0: 100% complete , Software Upgrade / VTR delivered in 1QFY14
   2D Only
   Delays due to needed operational software enhancements to improve numerical stability in coastal regions
   and required further evaluation and validation during a Navy exercise (closest opportunity was Trident Warrior July 2013) and new personnel on project.
2. 3DOG v1.0: 85% complete , Planned Transition w/ VTR 3QFY14.
   Delays due to issues with glider optimization code upgrade and operational enhancements to 3DOG.
3. BioCast v2.0 (3D): 40% complete , Planned Transition w/ VTR 3QFY15

Modeling, Sensing and Forecasting Ocean Optical Products for Navy Systems- TODS

FY13-14 Transition Plan Summary

- **TRANSITION APPROVAL STATUS:**
  1. FY13 TP approved, FY14 TP awaiting signatures from PMW120, CNMOC and OPNAV.

- **INPUTS**
  1. Satellite ocean color imagery (MODIS-Aqua, VIIRS, GOCI, and future Sentinel-3A and JPSS)
  2. Physical and optical glider data (quality controlled) and BSP/AEP data
  3. Numerical models (RELO-NCOM, HYCOM, etc.)

- **OUTPUTS / PRODUCTS:** Outputs will advance NRT high resolution fused oceanographic products to support a variety of naval missions *esp. MIW*:
  1. A 2D/3D forecast of coastal ocean optical properties for the performance surface
  2. Laser imaging systems performance surface (AQS-24), swimmer performance surface (visibility and vulnerability)
  3. A performance surface to support deployment of active and passive EO bathymetry systems (e.g. CHARTS)

- **ACCEPTANCE CRITERIA:**
  1. TECHEVAL at NRL with resulting VTR acceptance at NAVO (during fleet MIW exercise - compare 24 hour forecasts to next day images and independent profile data including Case II waters (if available exercises permit)). Validation Test Reports (VTR's) will include validation/data during MIW fleet exercises, other Navy leveraged exercises and the Northern Gulf of Mexico Test Bed
  2. Successful OPEVAL at NAVO that will involve installation and testing the transitioned software on NAVO systems for a 2 month period.

- ***OPERATIONS AND MAINTENANCE REQUIREMENTS***
  1. 2 months for OPEVAL and training will be required.
  2. 1 FTE will be required to run operationally after transition

Modeling, Sensing and Forecasting Ocean Optical Products for Navy Systems- TODS

IMPACT of Possible FY15 Funding Termination

- The full capability of the TODS' system to provide real-time/forecast 3D optical products and diver and laser system performance to MIW operations and mission planning cannot be completed by the end of FY14.

- Only the surface optical forecasting capability and real-time 3D optical properties can be completed with no 3D optical forecast capability.

- Impacts of FY15 funding cut:
  - No 3D optical forecast capability (water clarity, diver and SDV visibility /vulnerability and laser system performance) to support MIW mission planning and operations (detection, identification and clearing).
  - MIW Fleet operational impacts: loss in needed mission planning affecting time to complete clearing, a decrease in identification efficiency and an increase in asset and personnel risk.
  - Loss of talented NRL/contractor personnel familiar with the TODS system and software to other projects or new jobs and not available in FY16, loss of continuity on project requiring training of new personnel which would increase timelines and total cost to complete transition of TODS 3D optical forecasting capability.

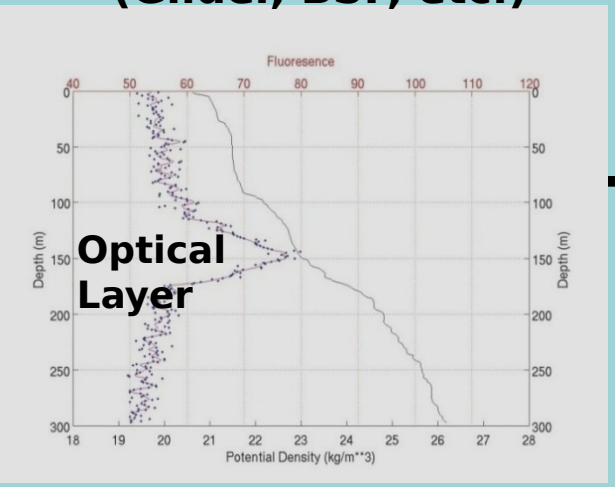
Outline

- **TODS Overview (BioCast, 3D Optical Volume, AQS System Performance)**
- **BioCast v1.0 VTR Summary**
- **Trident Warrior July 9-19, 2013 – Virginia Capes - ONR**
  - **Exercise Objectives**
  - **Optical Forecasts (BioCast v1.0)**
    - **24 Hour Forecast Example w/ Fusion of Satellite Optics and Physical Model.**
    - **Evaluation of 24 hour forecast to persistence.**
  - **TODS 3D Optical Generator (3DOG) Validation**
    - **Results of optimizing/tuning 3D optical model by combining Glider Optics and Physics combined with Satellite Surface (20 out of ~400 profiles spanning a 24 hour period - 3 days analyzed individually)**
    - **Preliminary validation results of 3D optical volume**
- **Summary**
- ***FY14/15 Plans***

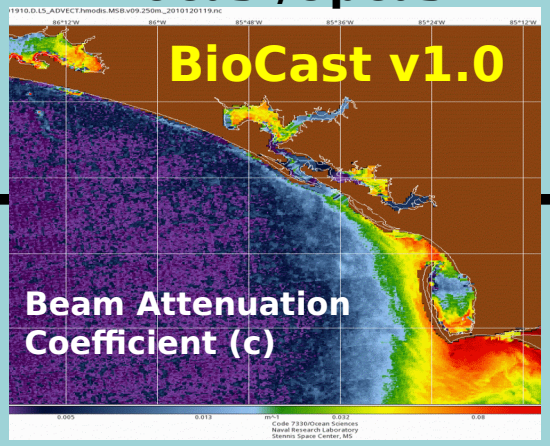
TODS Overview: Fusion of Glider Profiles, Satellite and Numerical Models to support AQS24 Operations

"Defining the optical environment for Navy Systems"

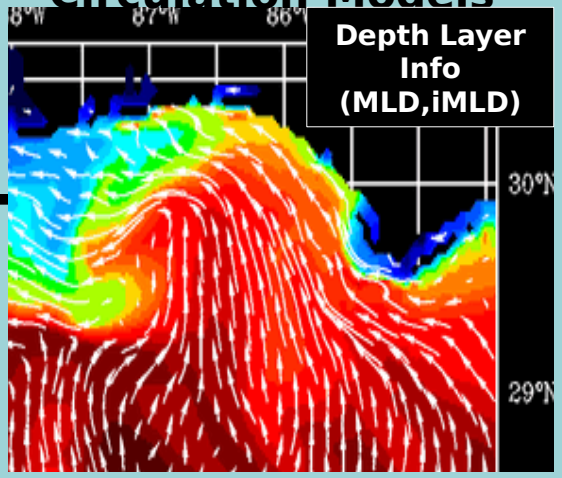
Vertical Optical Profiles (Glider, BSP, etc.)



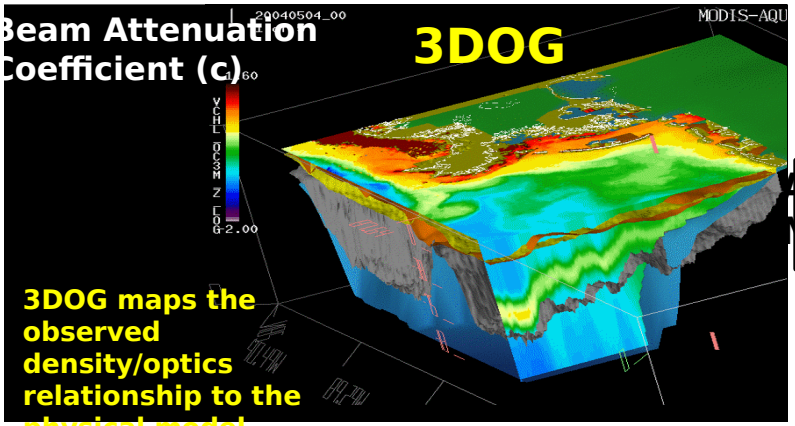
Nowcast / Forecast Satellite Optics BioCast/OpCast



Nowcast / Forecast Circulation Models



Optical Volume/Profiles & 3D Diver Visibility



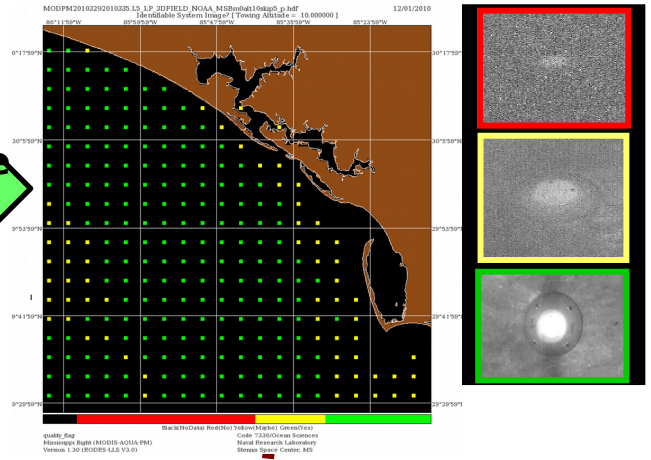
Insitu Physics/Optics Used to Tune Coeffs in 3DOG

AQS24 Performance Model (EODES)

Beam Attenuation Coefficient (c)

Nowcast/Forecast Performance Surface

Image Quality & Optimal System Towing Altitu



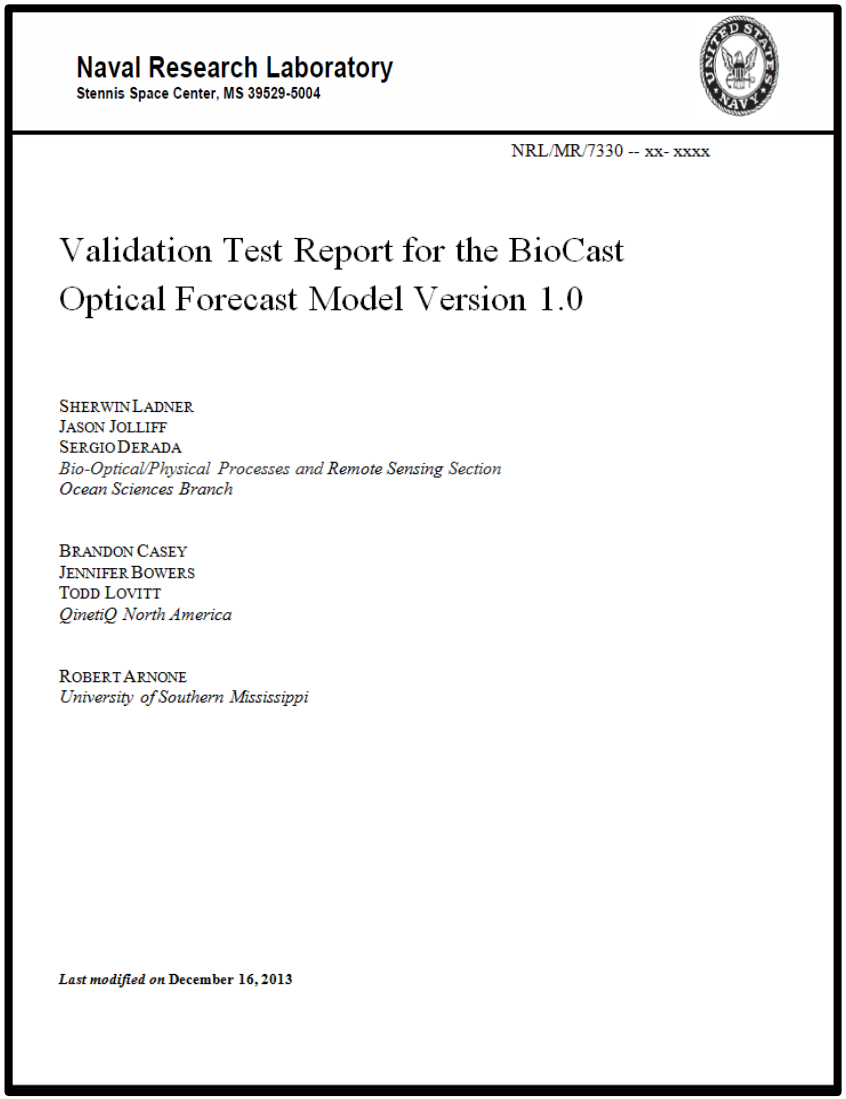
Transition of BioCast for Optical Forecasting (Surface Only) - Version 1.0

BioCast VTR –

- Capability to forecast surface bio-optical properties in support of shallow water Mine Warfare Operations (diver, laser imaging system performance – AQS24, lidar penetration depth and water clarity)
- Delivered to NAVO December 2013 (1QFY14)
- NAVO POC stated “VTR is acceptable and currently in the process of being accepted”
- OPTEST planned to start soon

VTR Highlights:

- 27 pages
- Test Case 1: Optical forecast validation in Miss Bight (Dec 2011- Oct 2012) with comparisons to OpCast v2.0 (2D advection)
- Results show BioCast had better error distributions
- Test Cast 2: Optical forecast (24 Hr) validation during Trident Warrior 2013.
- Results show forecast better than persistence.



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NRL/MR/7330 -- xx- xxxx

Validation Test Report for the BioCast Optical Forecast Model Version 1.0

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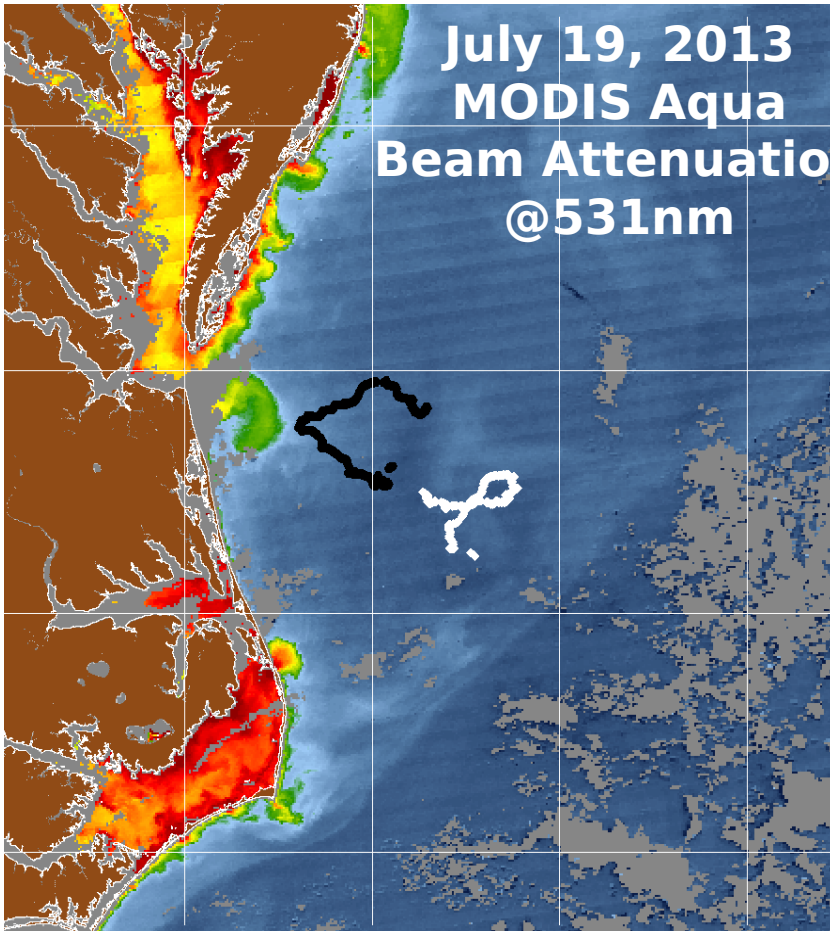
Last modified on **December 16, 2013**

Trident Warrior July 2013
2D/3D Underwater Optics Forecast

U.S. East Coast
Chesapeake Bay Virginia



OBJECTIVES:

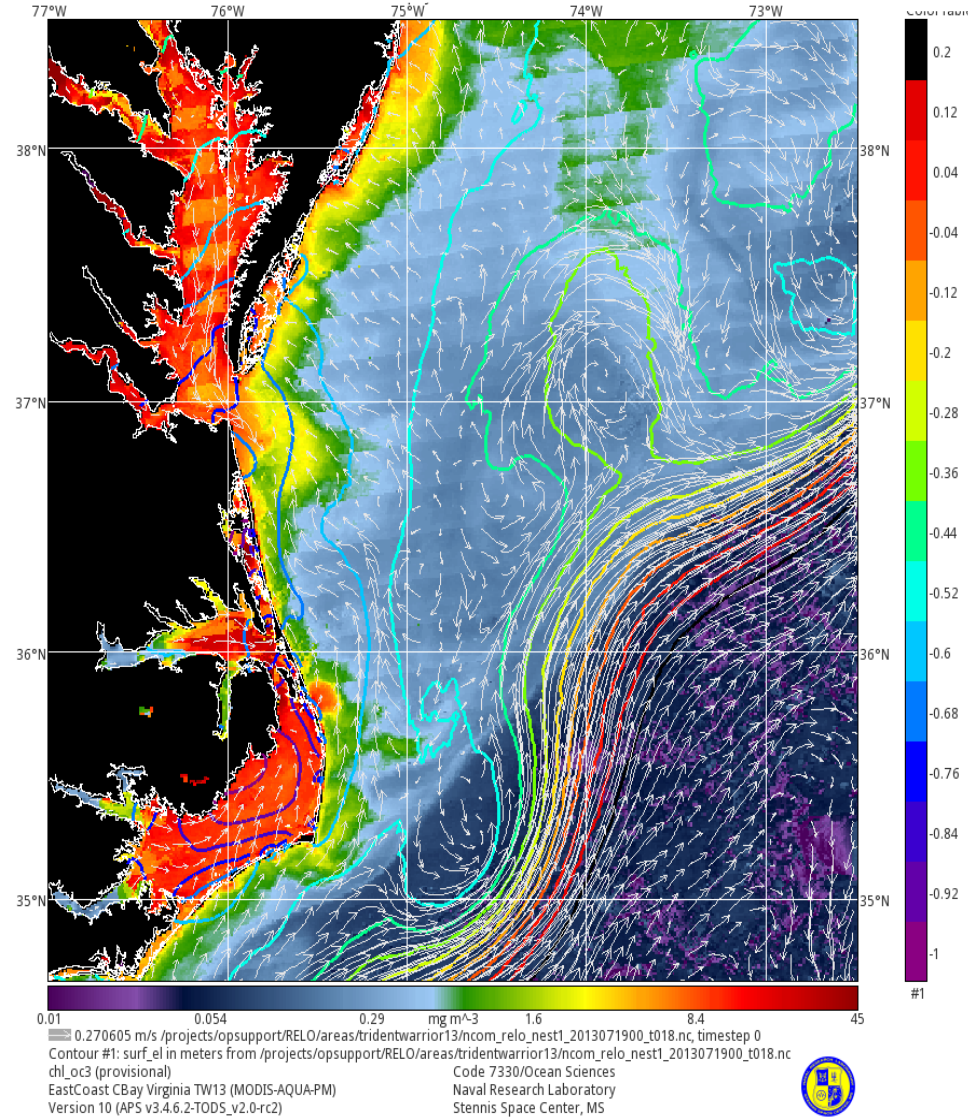
1. ***Produce 3D optical distributions for the exercise area:***
   - ***Couple surface satellite ocean color imagery with glider data, model results (MLD depth, intensity) – 3D Optical Generator (3DOG).***
   - ***Deploy gliders to tune vertical coefficients in 3D optical model.***
   - ***Evaluate 3DOG software operationally.***
   - ***Validate 3DOG Optical Volumes (VTR).***

2. ***Forecast short-term surface optical distributions:***
   - ***Run and evaluate BIOCAST***

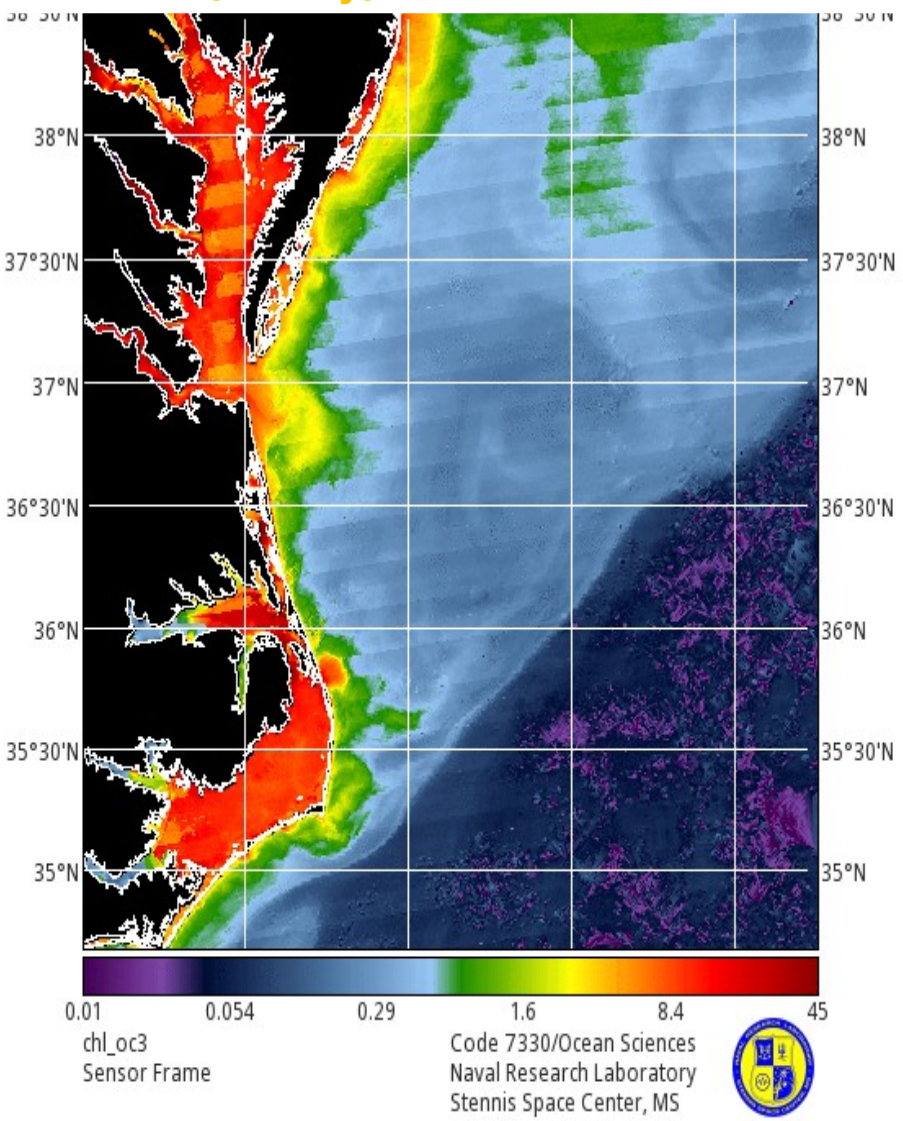
ace forecast

Forecasting Surface Bio-Optical Properties
Trident Warrior 13 Merging Satellite Bio-Optical Properties and Modeled Currents - BIOCAST v1.0

19, 2013 MODIS Aqua Chlorophyll Initialization Field w/ Model Currents & SSH Contours



19, 2013 MODIS Aqua Chlorophyll ur (Hourly) Forecast - Animation



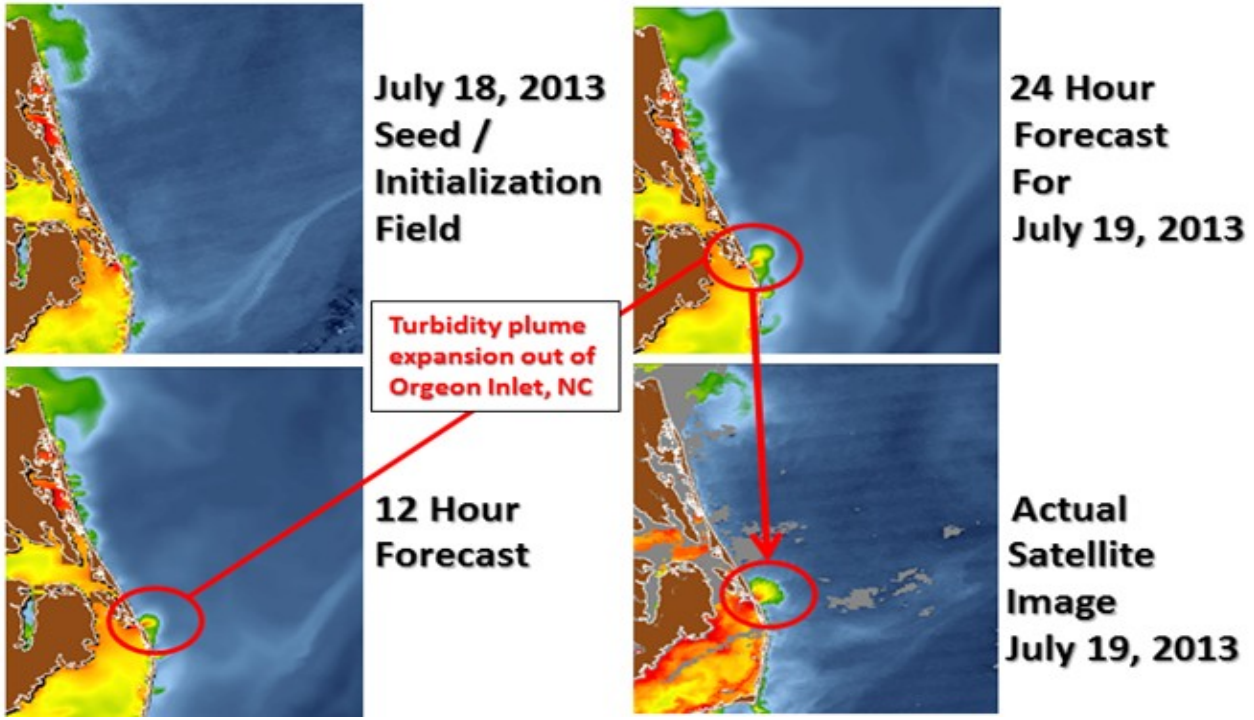
Forecasting Surface Bio-Optical Properties

Trident Warrior - Chesapeake Bay, VA – *July 18, 2013*

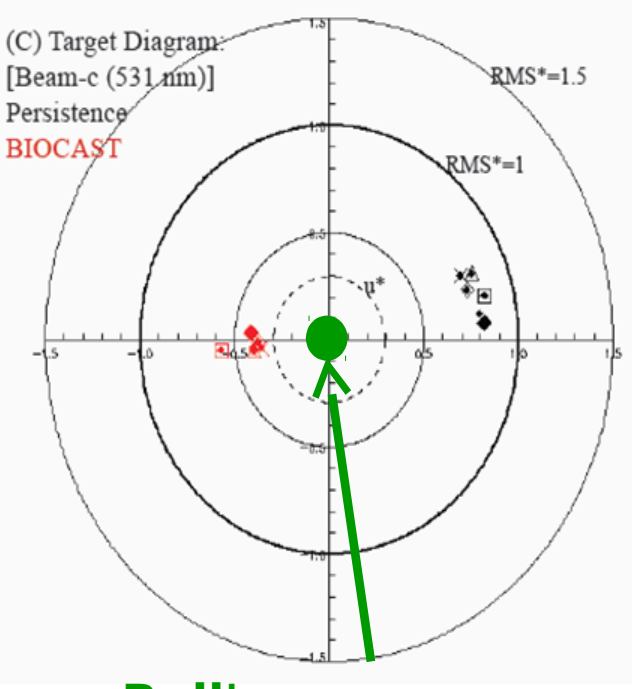
Forecast Steps:

Seed the Model with Satellite Bio-Optical Products → Advect Satellite Properties forward (hourly steps) Conservative Tracers → Compare with Next Days Satellite Bio-Optical Products

c531nm / Optical Field



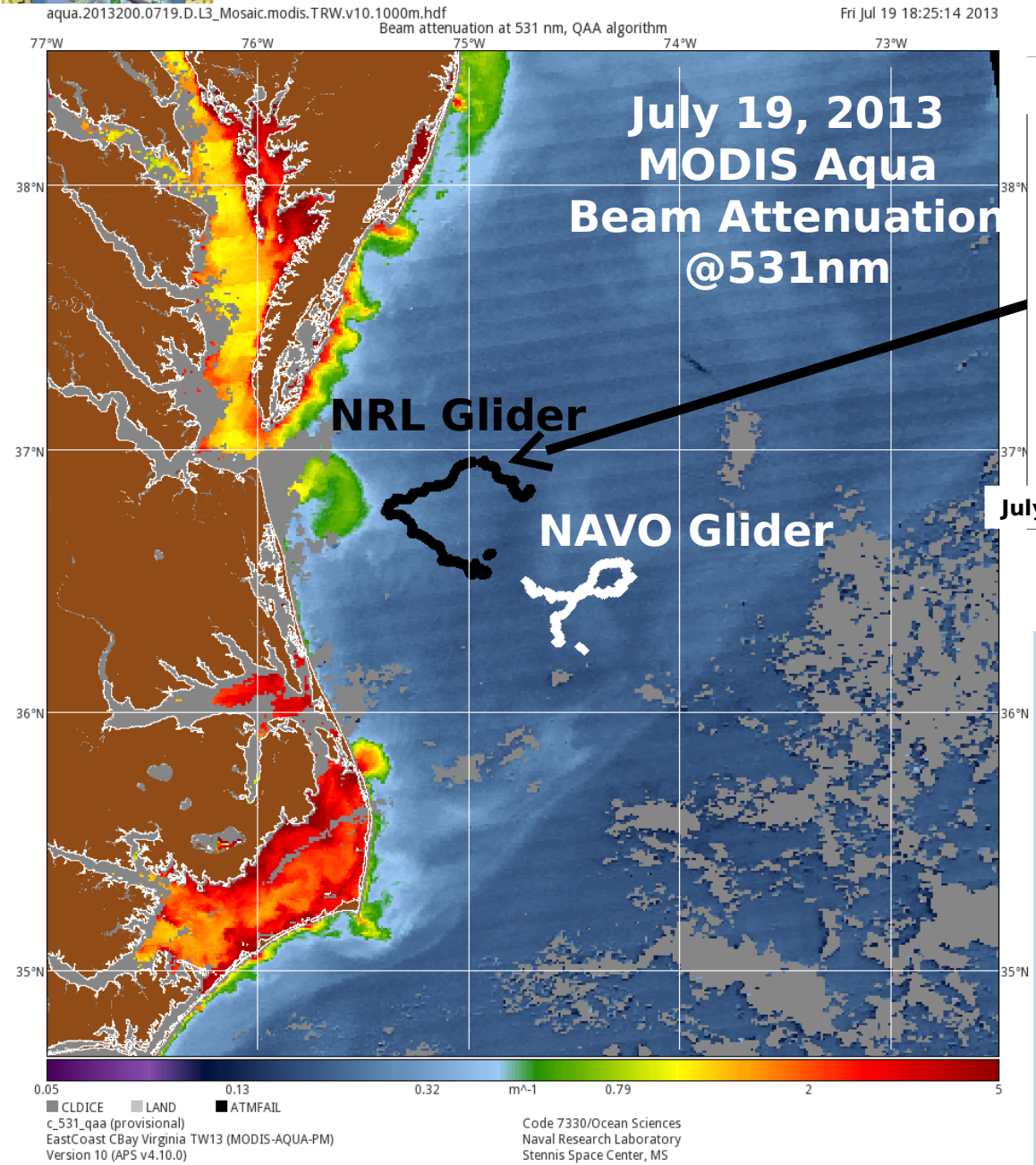
BioCast vs Persistence



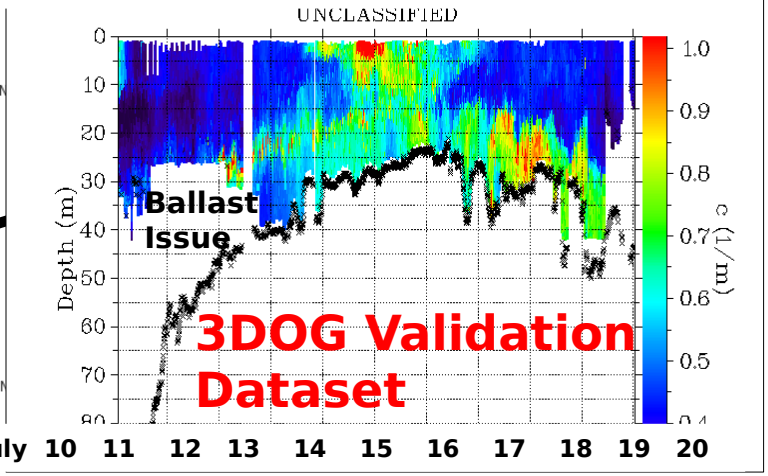
Bull's-eye = no error

Statistical summary diagram compares 30-day latest pixel composites (persistence) against the next-day MODIS satellite product (black) and BIOCAST 24-hour forecast against the same next-day MODIS product (red). Statistics are generated from 60-days

Predicting the 3D Optical Environment by Fusing Satellite, Gliders and Models during Trident Warrior July 2013



NRL Glider (sl082) Beam-c 531nm



- Selected optical profiles (20) were used to generate/tune coefficients for 3D optical model
- Non-selected optical profiles (330) are being used for validation
- NAVO glider omitted from 3DOG evaluation due to issue with elevated optics in deep ocean.

3DOG Glider Optimization – Tuning Coefficients

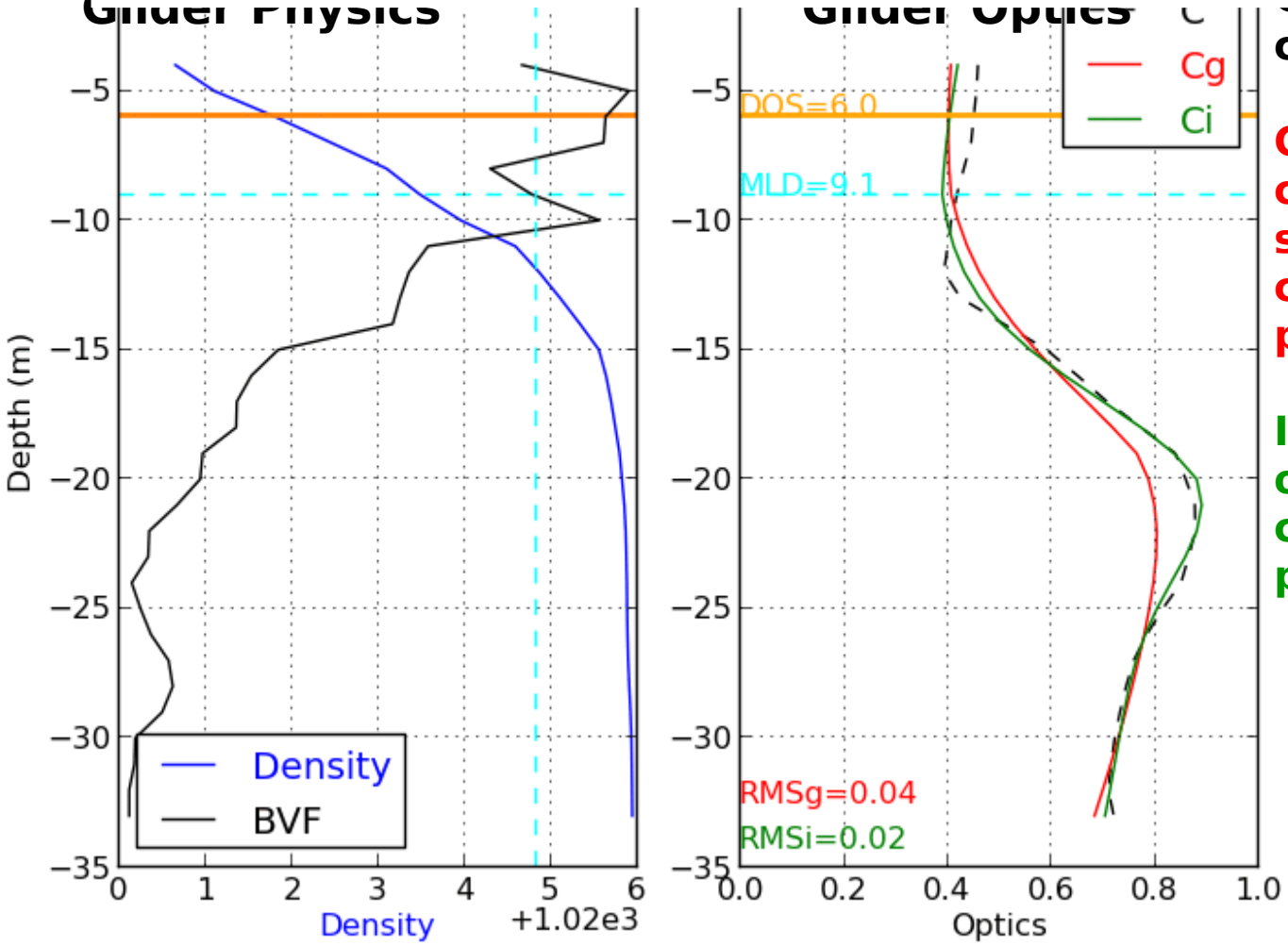
Trident Warrior – July 17, 2013

3DOG Predicted Beam Attenuation 531nm Profiles

Defining Regional Optical/Physical Relationship

Density / MLD Predicted Optics

Observed &



Glider Insitu Beam-c

Global optimized coefficients - 20 selected profiles covering 24 hour period

Individually optimized coefficients - each profile

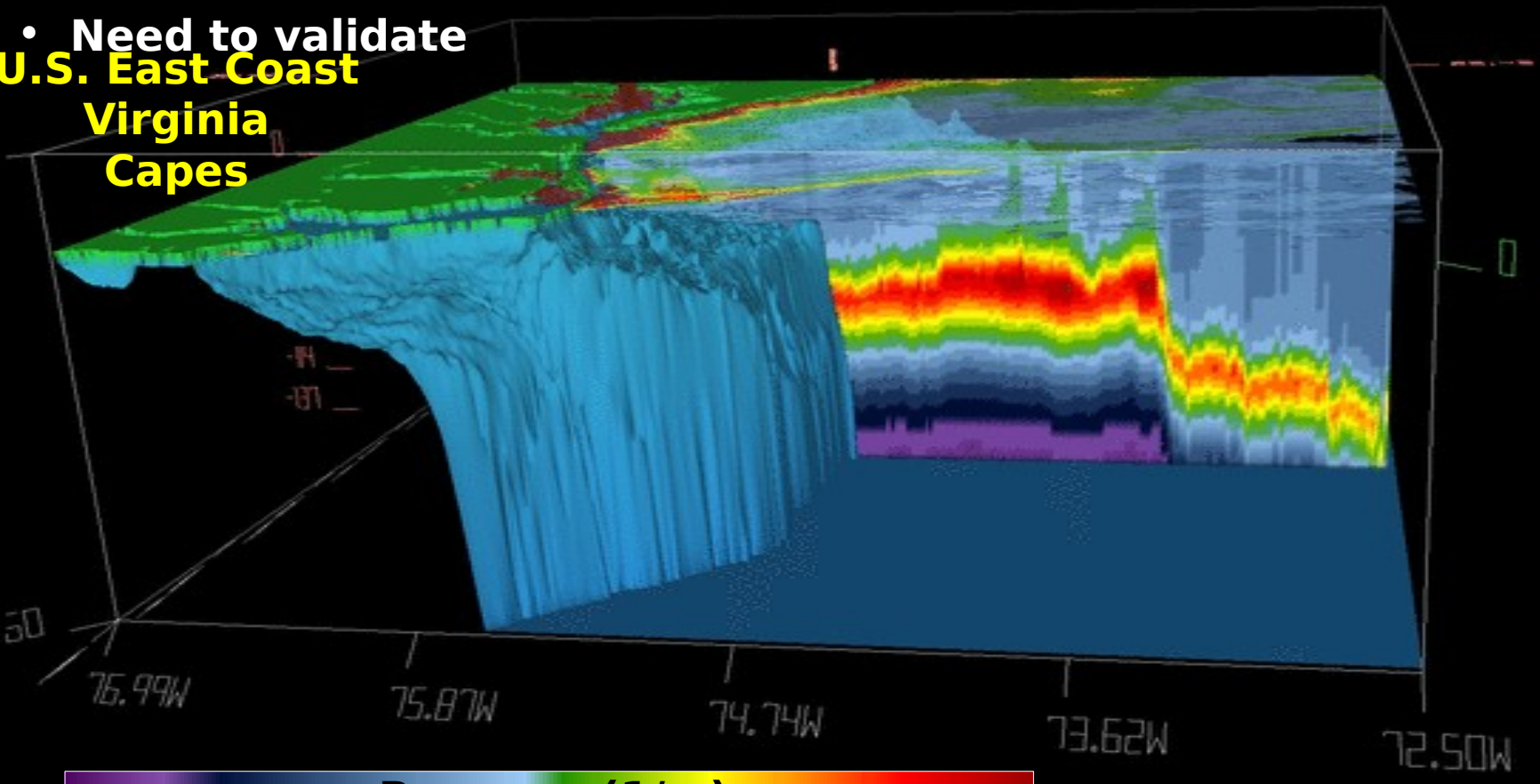
Mean RMS
0.05
0.02

Trident Warrior 2013 July 17, 2013
3DOG Volume - Beam Attenuation 531nm

Preliminary Results Suggest:

- Coastal/shelf overturning, mixing, resuspension/sedimentation/nephloid layers
- Optical layers migrating up the shelf
- Interactions between surface features and subsurface
- Need to validate

U.S. East Coast
Virginia Capes



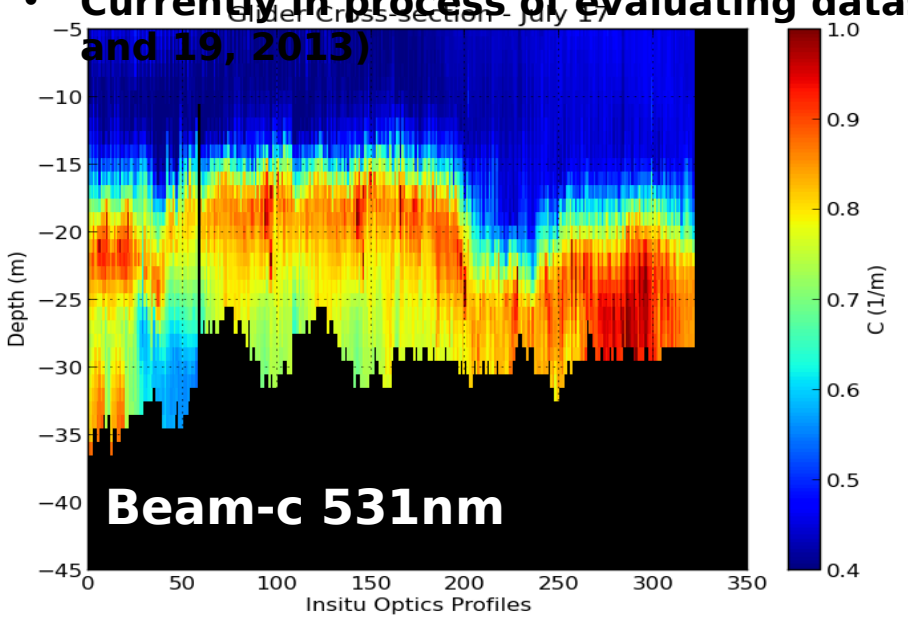
Beam-c (1/m)

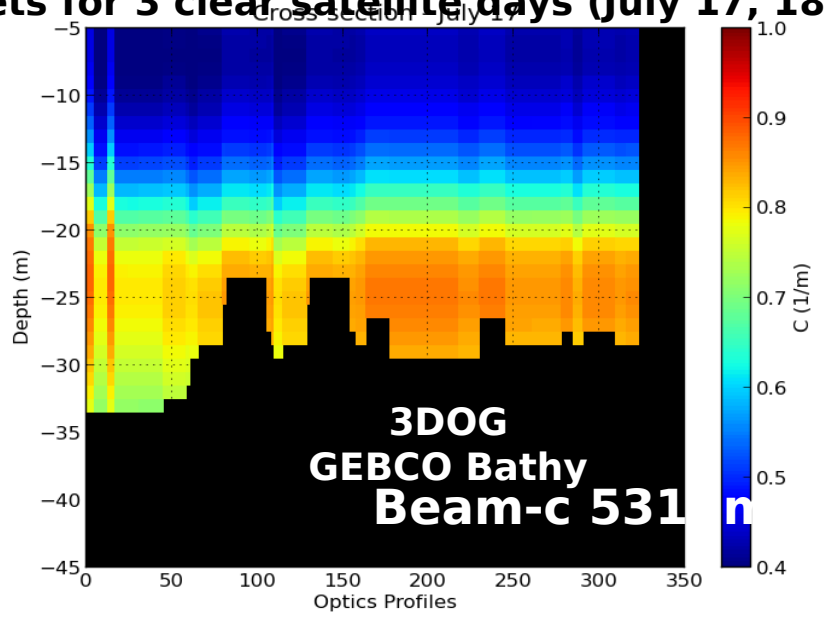
0.34 0.47 0.64 0.88

Bathymetry generated using Bathygen / GEBCO database

3DOG Validation - Trident Warrior 13 – July 17, 2013
Preliminary Validation Results

- **An optical (beam attenuation 531nm) layer is observed in glider profiles near bottom. Preliminary 3DOG results mimic the same optical layer.**
- **The relationship between the observed and modeled optical fields is dependent on the fidelity of the physical model to the observations.**
- **Differences between observed and predicted possibly due to model bathy (flat bottom) and vertical resolution (5-10m bins > 10m) not capturing fine scale details in observations, MLD selection and bottom turbulence/sediment resuspension.**
- **Observations span 24 hours whereas satellite and model are coincident/static (time of satellite overpass) in 3DOG.**
- **Currently in process of evaluating datasets for 3 clear satellite days (July 17, 18 and 19, 2013)**





Tactical Ocean Data System (TODS)

Modeling, Sensing and Forecasting Ocean Optical Products for Navy Systems

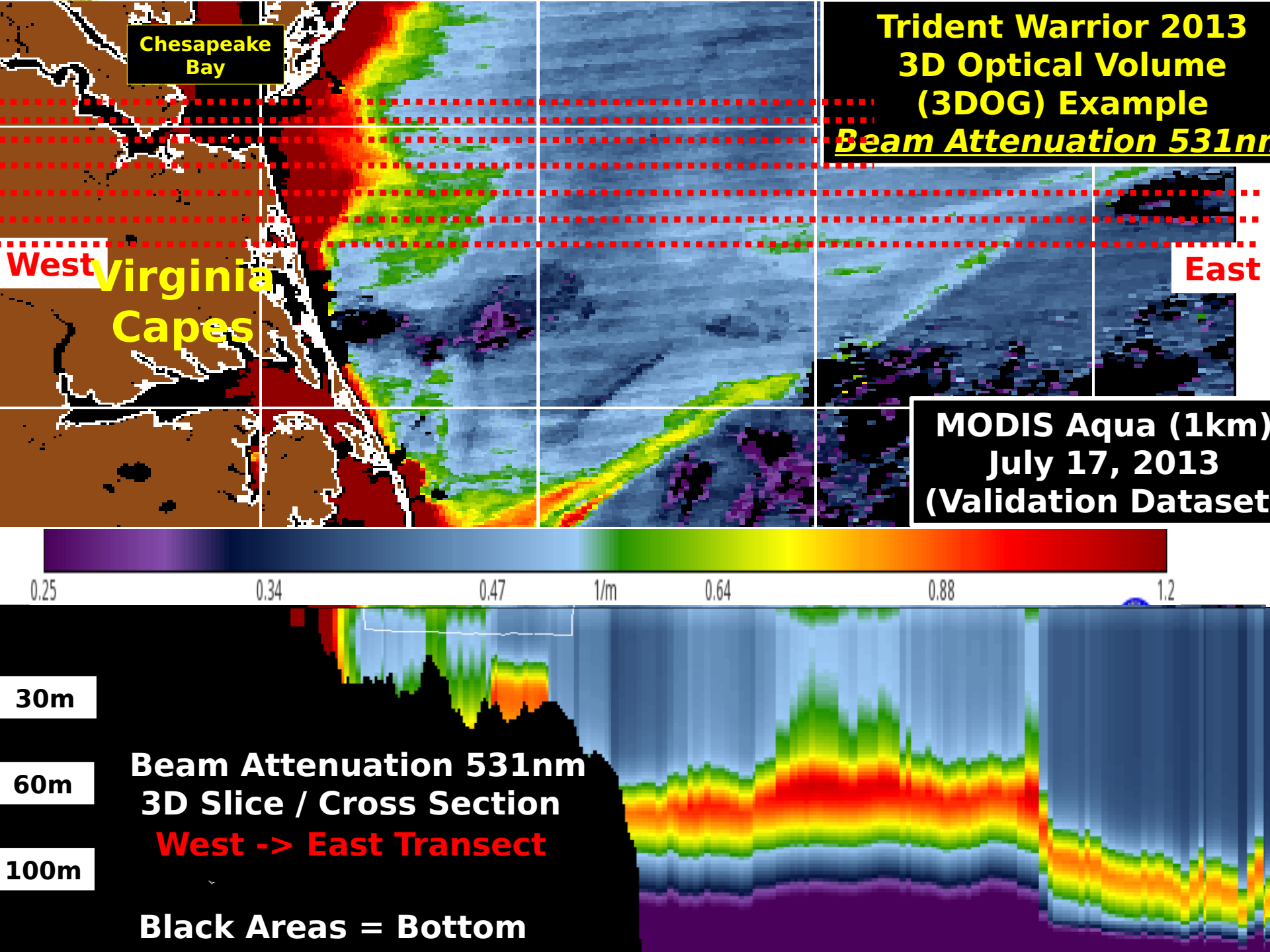
- **Summary:**
  - Trident Warrior July 2013 TODS Operational Evaluation
    - BioCast v1.0 24 hour 3D forecasts outperformed OpCast v2.0 2D forecast as compared to next day's satellite optical product in MissBight and persistence (using previous day's image as next day's forecast) during Trident Warrior July 2013 – VTR delivered 1QFY14 – OPTEST to start soon.
    - Both systems BioCast v1.0 and 3DOG v1.0 performed well during operational assessment during Trident Warrior 2013.
    - Improvement to glider optimization (evolutionary solver – Linux API upgrade) performed very well during Trident Warrior 2013 producing better coefficients in less time for the 3D Optical Generator (3DOG) component.
    - 3DOG validation underway and initial results show good performance.
  - Need data collected by multiple gliders simultaneously in future (Navy or leveraged exercises). Will work closely with NAVO to find opportunities or glider data. In the past year or two the opportunity to deploy in Navy exercises has been limited.
  - This projects goal is to depict the real time and predict the

Tactical Ocean Data System (TODS)

Modeling, Sensing and Forecasting Ocean Optical Products for Navy Systems

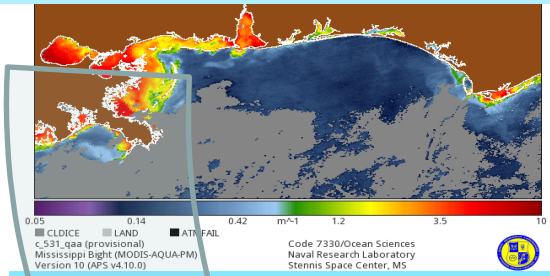
- **Future Plans:**
  - **3D Optical Generator (3DOG) transition/VTR (3QFY14).**
  - **EODES transition (4QFY14).**
  - **Upgrade 3D optical forecasting capability BioCast v2.0 w/ new laser/EO system tow height predictions using beam-c (attenuation length) data from real-time and hourly forecast 3D optical volumes (3QFY15).**
  - **Upgrade EODES AQS laser imaging system performance software to support the AQS-20 and threading to increase speed will need to be done (4QFY15).**
  - **3DOG Upgrade improving 3D "SEED Field" using advanced 3D blending techniques – model data fusion to generate a real-time analysis field (4QFY15).**
  - **Investigate and implement additional Mixed Layer Depth (MLD) algorithms for 3D optical model (3DOG).**
  - **Need to deploy multiple optics gliders in future Navy exercises. Working closely with NAVO to make this happen for 3DOG validation. Had a few opportunities but had issues with gliders. In the past year or two the opportunity to deploy in Navy exercises has been limited.**
  - **Planned TODS completion in 4QFY15 with improved TODS**

Extra Slides

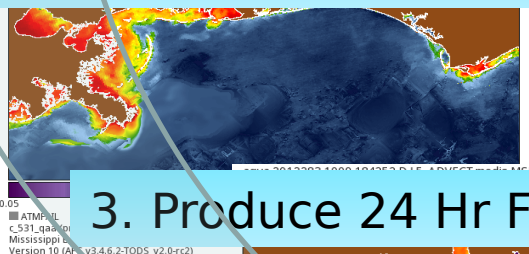

Chesapeake Bay
Trident Warrior 2013
3D Optical Volume
(3DOG) Example
Beam Attenuation 531nm
West
Virginia
Capes
East
MODIS Aqua (1km)
July 17, 2013
(Validation Dataset
0.25
0.34
0.47
1/m
0.64
0.88
1.2
30m
60m
100m
Beam Attenuation 531nm
3D Slice / Cross Section
West -> East Transect
Black Areas = Bottom

BioCast Validation 6 Step Procedure

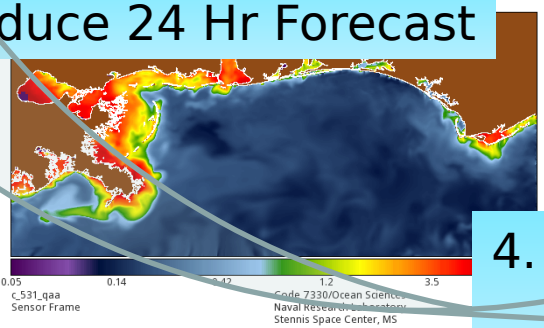
1. Today's Optical Image (c531nm)
ctober 9, 2012



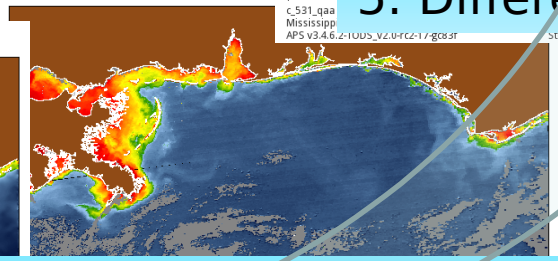
2. Create Initialization Field



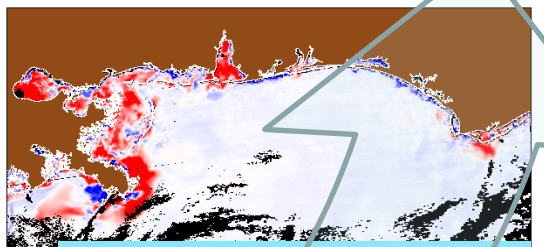
3. Produce 24 Hr Forecast



4. Compare to Next Day's image October 10, 2012



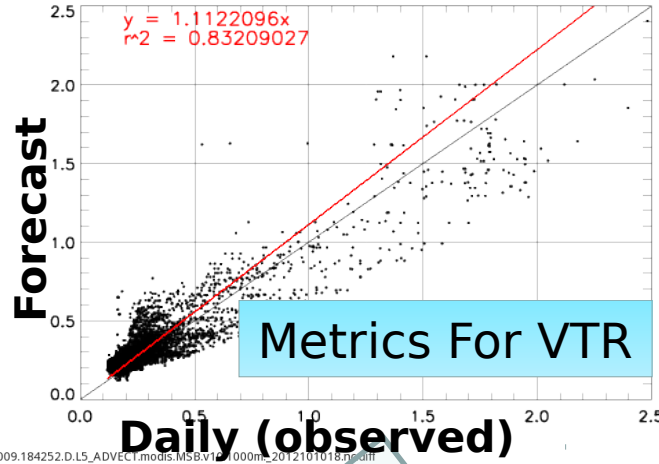
5. Difference Field



6. Stats (Forecast vs Measured

Beam-c @531nm

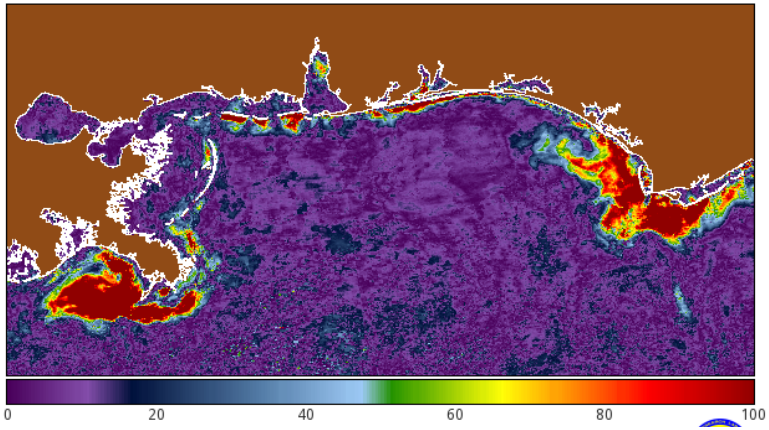
- r^2 0.83
- Y = 1.1122x



Metrics For VTR

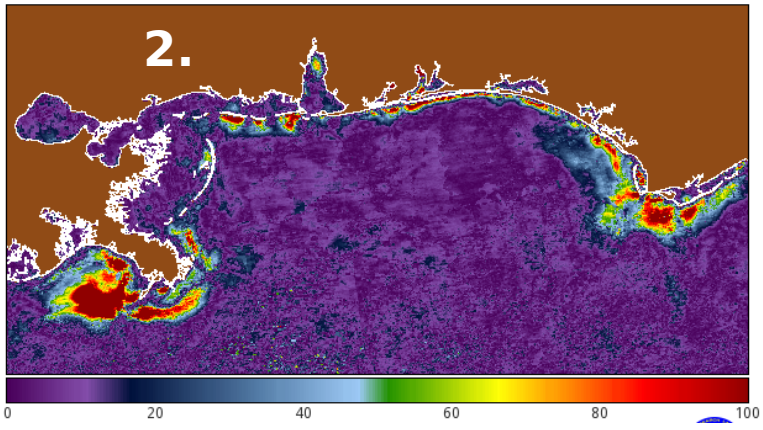
10 Month Mean Forecast Statistics
(December 2011 – October 2012)
MODIS-Aqua Beam Attenuation Coefficient (c) @ 531nm

OpCast (Mean Absolute % Error)



Percent

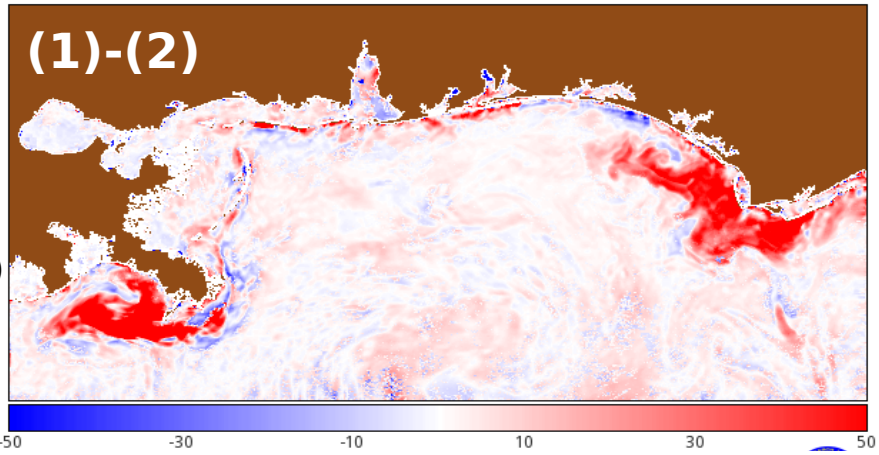
BioCast (Mean Absolute % Error)



Percent

MAPE = |Forecast(24hr)-Observed| / Observed * 100

Difference Image
MAPE
OpCast(1) – BioCast(2)



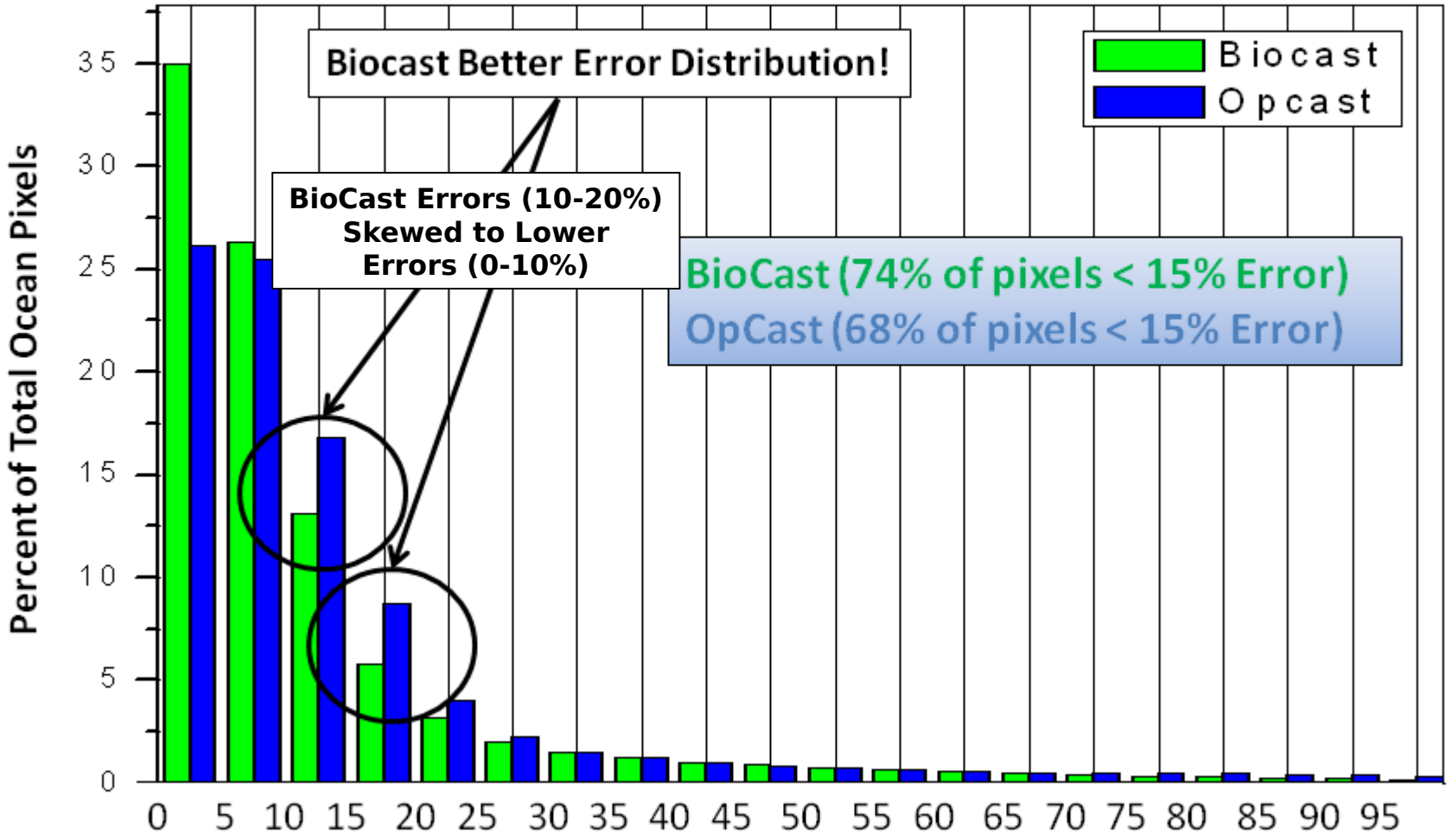
Difference in Percent

Red = BioCast performs better (70% of total pixels)

Blue = OpCast performs better.

10 Month Mean Forecast Statistics
Beam Attenuation Coefficient (c @531nm)

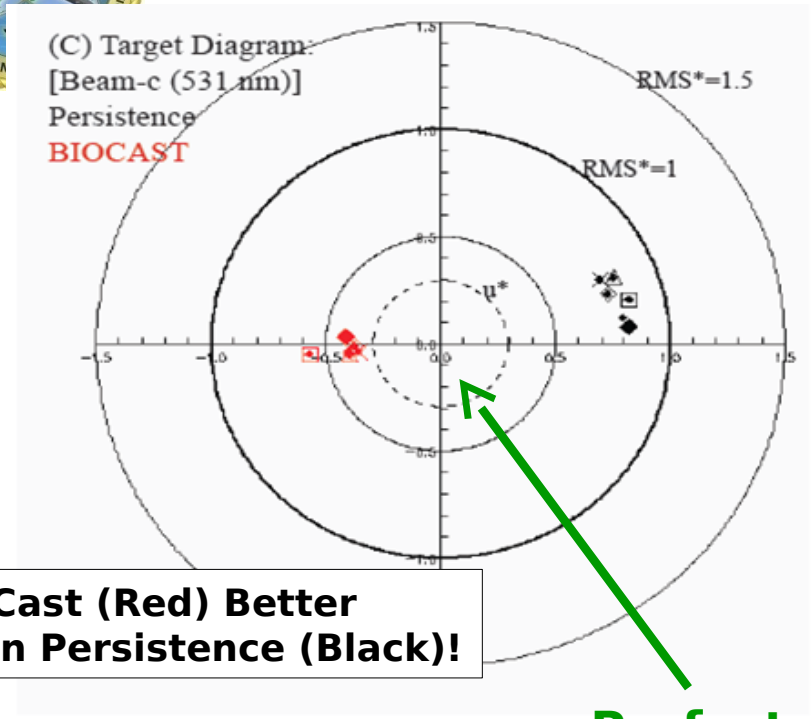
Frequency Distribution of Errors

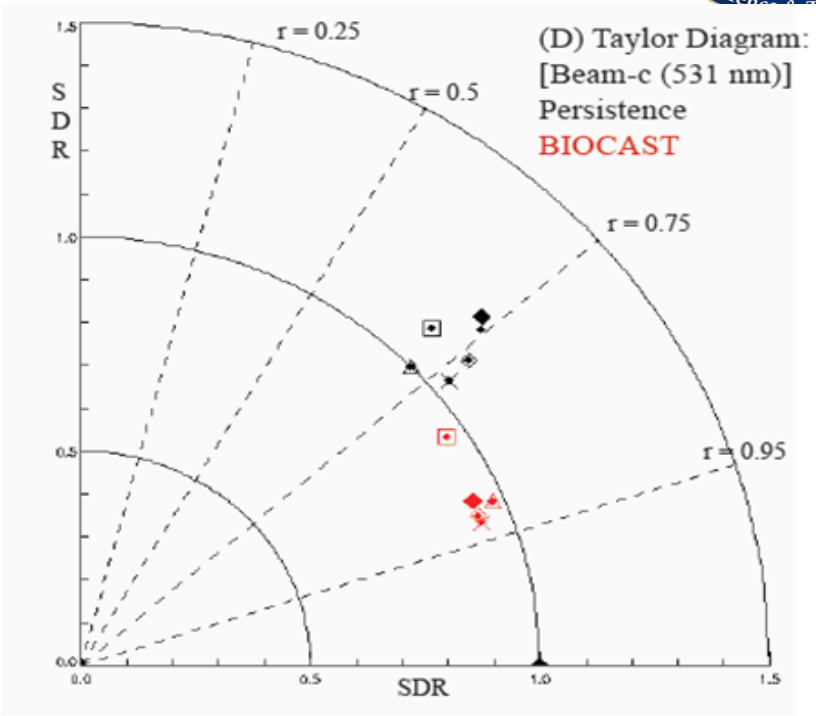


Mean Absolute Percent Error (Binsize=5%)

MAPE = |Forecast(24hr)-Observed| / Observed * 100

BioCast v1.0 Validation (Forecast vs. Persistence) During Trident Warrior 2013





BioCast (Red) Better Than Persistence (Black)!

Perfect

Range from Shoreline: 10 km. 30 km. 60 km. 109 km. 209 km. 249 km

Figure: Statistical summary diagrams comparing 30-day latest pixel composites (persistence) against the next-day MODIS satellite product (black) and BIOCAST 24-hour forecast against the same next-day MODIS product (red). Statistics are generated from 60-days of 'next-day' comparisons (1 July – 30 August 2013). The range refers to the subset of image pixels selected for statistical analysis using a distance from the shoreline criterion. Correlation (r) improves as the distance from the shoreline increases since the forecast products all mimic the general offshore bio-optical gradient. The target diagrams are a measure of bias (Y-axis) and unbiased RMS (X-axis). The distance from the origin is the total RMS score. Product Beam-c @531nm